MICRO PUMP POWERED BY PIEZOELECTRIC DISK BENDERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to pumps and more specifically to a pump for implantation into the human body.

2. Description of the Prior Art

In the field of fluid delivery systems for use in the human body, the present devices are either not wholly implantable or the devices are not directly controllable or capable of preventing blow through caused by pressure applied to the inlet of the pump. The latter feature is necessary to insure that potentially dangerous overdoses of drugs or hormones are inadvertently forced into the host by sudden pressure on the reservoir, as might be caused by a blow. A miniature implantable roller type pump is described by G. D. Summers in "A New and Growing Family of Artificial Implanted Fluid Devices," *Am. Soc. Art. Int. Organs* 16: 219 (1970). This type of pump requires an extracorporeal power source which is supplied by an external motor magnetically coupled to the pump through the skin. Feedback control would require a rather complicated arrangement of the implanted and extracorporeal units. A fully implantable fluid delivery system is described by P. J. Blackshear et al., in "The Design and Initial Testing of an Implantable Infusion Pump," *Surgery, Gynecology and Obstetrics* 134: 51 (1972). It is powered by evaporation at a constant pressure of about ½ atmosphere of perfluoropentane isomers in an enclosed liquid-vapor system. A constant rate of outflow is maintained by a calibrated resistance in the outflow tube and by the viscosity of the delivered fluid. Feedback control in this system would require active valving of the outflow. But the lack of control over pumping pressure opens the possibility that the entire contents of the reservoir could empty into the host at a pressure of about 400mm Hg should the valve fail.

Both of the above described systems are capable of discrete quantitative delivery of aliquots of solution but each has serious drawbacks. There thus exists a need in the implantation field for a completely implantable fluid delivery system which is blow through proof, is susceptible to uncomplicated feedback control, is able to deliver discrete aliquots with reliability and requires sufficiently low power to permit a relatively long implantation life.

SUMMARY OF THE INVENTION

The problems of the prior art are solved by the miniature pump of the present invention which includes a variable volume chamber consisting of two apposed piezoelectric disk benders, forming a bellows, connected to a solenoid valve. A rectangular wave pulse generator directly activates the opening and closing of the solenoid valve and indirectly, through a step-up transformer, activates the flexing of the disk benders. This transformer provides a high voltage necessary for efficient operation of the disk benders. Also when properly activated by the pulse generator, the inductance of the secondary winding of this transformer, the resistance of the winding, and the capacitance of the disk benders, act as a phase shift network to provide the desired relationship between pump stroke and valve opening. The volume delivery per stroke of the pump can be under 0.2 microliters and the total delivery is a function of the number of pulses from the generator. Optimum performance is achieved by setting the frequency of the pulse generator to the hydrodynamic resonant frequency of the fluid system and setting the duration of the pulse so as to achieve proper phasing between motion of disk benders and valve.

OBJECTS OF THE INVENTION

The principal objective of the present invention is to provide a pump for a controllable fluid delivery system which can be made completely implantable. To accomplish this, it was necessary for the present invention to achieve the following objects:

1. capability for simple control of output to permit reliable feedback regulation;
2. ability to deliver extremely small volumes without employing small precision parts so that the pump can perform over long periods without failure;
3. low power consumption to permit long duration of function from implanted batteries;
4. small size to permit incorporation into a complete system of sensors, amplifiers, power supply, etc.
5. A valving arrangement such that it is not possible to force fluid through the pump when the pump is not active.

Other objects, advantages and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIGS. **1A** and **1B** are schematics of a preferred embodiment of the present invention in an exhaust stroke and in an intake stroke, respectively;

FIGS. **2A, 2B** and **2C** are tracings from an oscilloscope record showing simultaneous display of A (voltage from the signal generator; B) voltage applied to the piezoelectric elements, and C) isometric pressure (mm Hg) in the variable volume chamber;

FIG. **3** is a plot of data from a working pump showing the following as a function of driving frequency from the rectangular wave generator: curve A) optimum interval (milliseconds) between pulses to obtain maximum output pressure at a given frequency (Hz); curve B) maximum output pressure (mm Hg) obtainable at a given frequency (Hz); and curve C) maximum output volume per stroke (microliters) obtainable at a given frequency (Hz). This was obtained with resistance to outflow reduced to a minimum;

FIGS. **4A** and **4B** are wave forms of the voltage across the transformer secondary winding and the voltages across the output of the rectangular wave generator, respectively, at 20Hz. FIGS. **4C** and **4D** are wave forms of the voltage across the transformer secondary winding and the voltage across the output of the rectangular wave generator, respectively, at 60Hz;

FIG. **5** is a plot of data from a working pump showing output volume in microliters per pulse (horizontal scale) as a function of back pressure in mm Hg developed against a resistance to outflow; and

FIG. **6** is a plot of data from a working pump showing maximum output pressure (mm Hg) of the pump as a function of rectangular wave generator voltage.